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Parallel Computation Of Sensitivity Derivatives With Application to Aerodynamic Optimization of a Wing

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NASA Langley Research Center

Computational Aerosciences Workshop

NASA Ames Research Center, August 25-27, 1998

Outline

- *Introduction*
- *Parallel Approach and Scaling*
- *Parameterization And Design Variables*
- *Comparison With Finite Differences*
- *Wing Optimization*
- *Summary*

Introduction

- For gradient-based optimization, need fast, accurate derivatives of objective functions and constraints
- Code differentiation is exact and consistent with flow solver; tedious to do by hand, but automatic differentiation (AD) tools make it relatively simple
- AD tools have been developed by Argonne National Laboratory and Rice University
  - ADIFOR - differentiates code as it runs in “forward mode”
  - ADJIFOR - differentiates code as it operates in “reverse mode” to mimic adjoint formulation

Introduction (cont.)

- ADIFOR is mature technology - used for the current work; ADJIFOR has only recently been developed and is the focus of the next presentation
- ADIFOR applied to the NASA Langley CFL3D code
  - Solves Euler or Thin-Layer Navier Stokes
  - Point match / patched / overset structured grids
  - Steady state or time accurate
- Computational cost of derivative calculation via ADIFOR roughly scales with N_{DV}
- Reduce wall time by using parallel processing

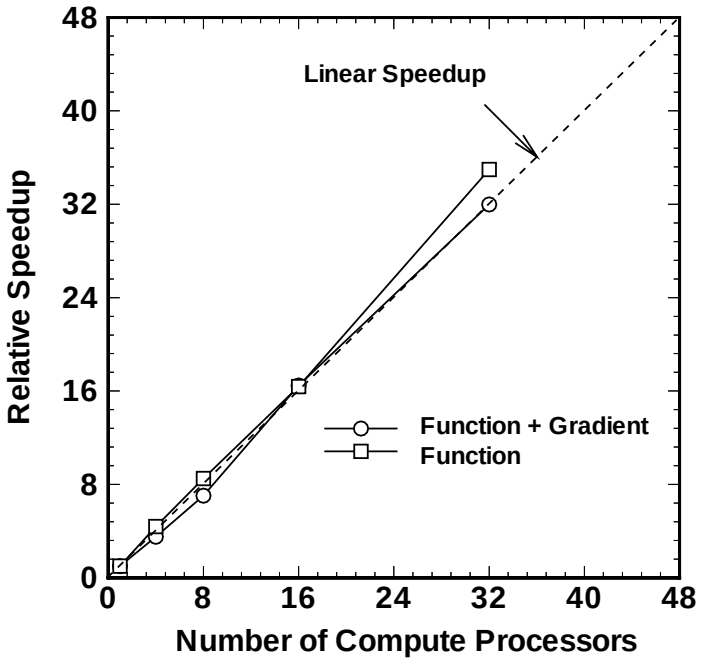
Parallel Approach

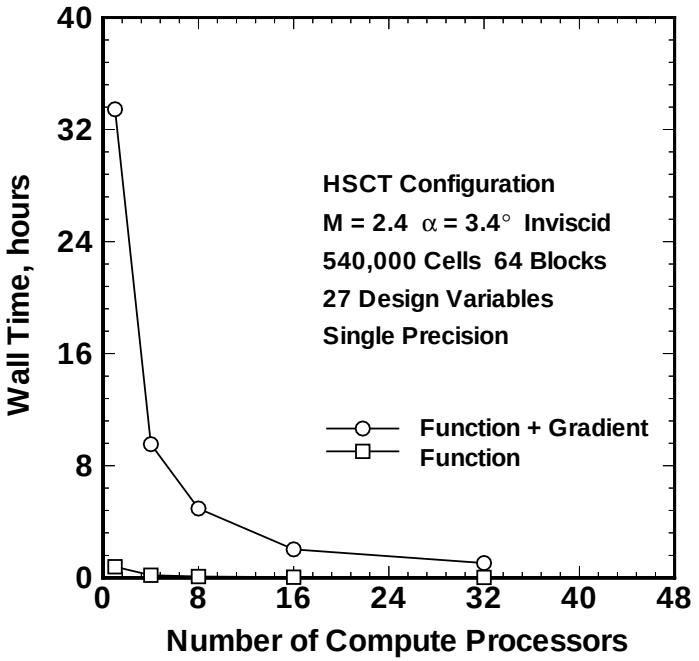
- Can utilize multiple processors to reduce wall time in two ways:
  - "Coarse grain" parallelization by computing only a subset of N_{dv} on a CPU (not considered here)
  - "Fine grain" parallelization by breaking the domain into a number of smaller blocks, and computing each block on a different CPU
  - For large problems, can combine both methods
- CFL3D (+AD) parallelized across blocks via MPI
- For efficiency, parallel code must scale with number of CPUs

Scaling

1-32 Compute Processors on 195 Mhz Origin 2000

HSCT Configuration 540,000 Grid Pts 27 DVs





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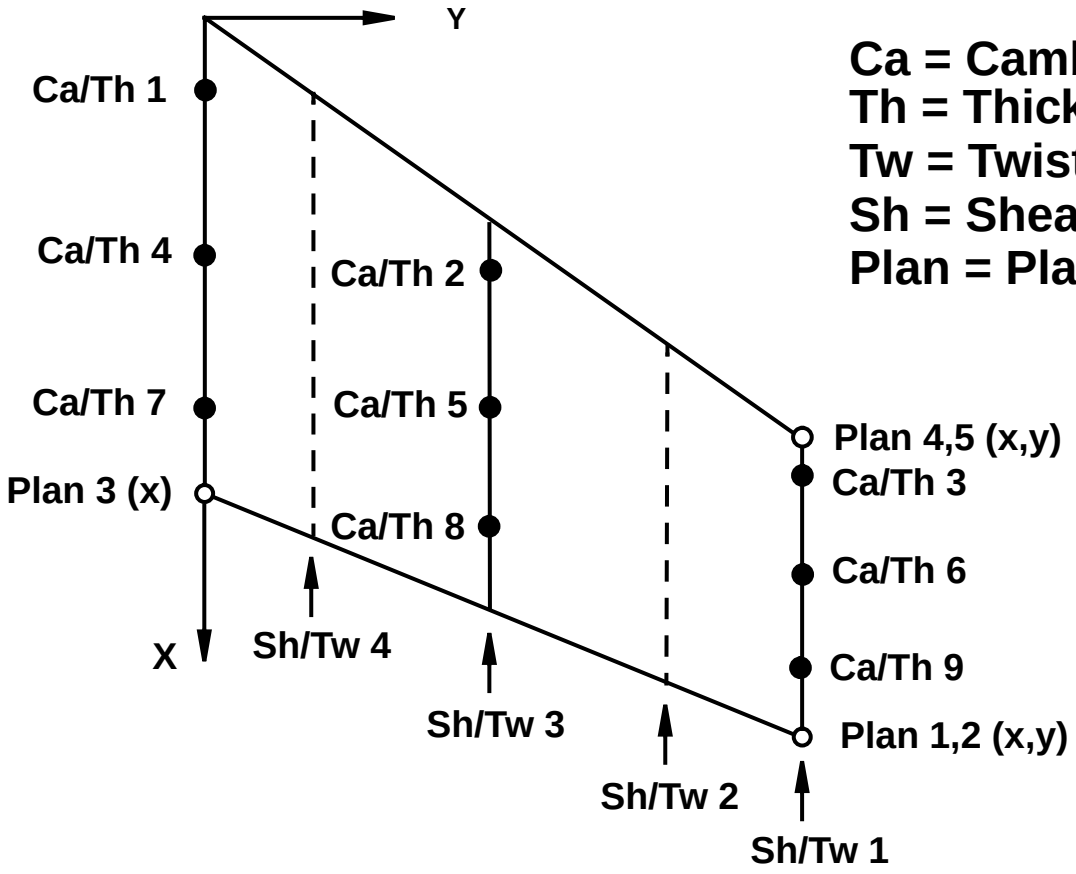
Parameterization

- *New scheme developed by Samareh to parameterize existing CFD and CSM grids*
- *Direct application to aero-structural interaction*
- *Bezier net placed around baseline mesh*
- *Control points can be used directly as design variables, or linked to design variables such as thickness, camber and twist*
- *Mesh is "rubberized" and can be twisted, compressed, etc., but retains original topology*

Design Variables - ONERA M6

- *52 parameters used to define the surface mesh, 31 of these chosen as design variables:*



Ca = Camber (9)
Th = Thickness (9)
Tw = Twist (4)
Sh = Shear (4)
Plan = Planform (5)

Comparison With Finite Differences

Central Finite Differences With $h = 1 \times 10^{-6}$

Derivative.	AD (DP)	FD (DP)	% error (DP)	AD (SP)
dC_L/d(Plan 3)	-0.08333	-0.08333	0.0	-0.08333
dC_L/d(Tw 3)	-0.02944	-0.02944	0.0	-0.02944
dC_L/d(Sh 3)	+0.02001	+0.02001	0.0	+0.02001
dC_L/d(Th 8)	*+0.43321*	+0.43321	0.0	*+0.43323*
dC_L/d(Ca 8)	+2.8380	+2.8380	0.0	+2.8380
dC_D/d(Plan 3)	-0.01065	-0.01065	0.0	-0.01065
dC_D/d(Tw3)	-0.00246	-0.00246	0.0	-0.00246
dC_D/d(Sh 3)	-0.00138	-0.00138	0.0	-0.00138
dC_D/d(Th 8)	+0.07016	+0.07016	0.0	+0.07016
dC_D/d(Ca 8)	+0.16467	+0.16467	0.0	+0.16467

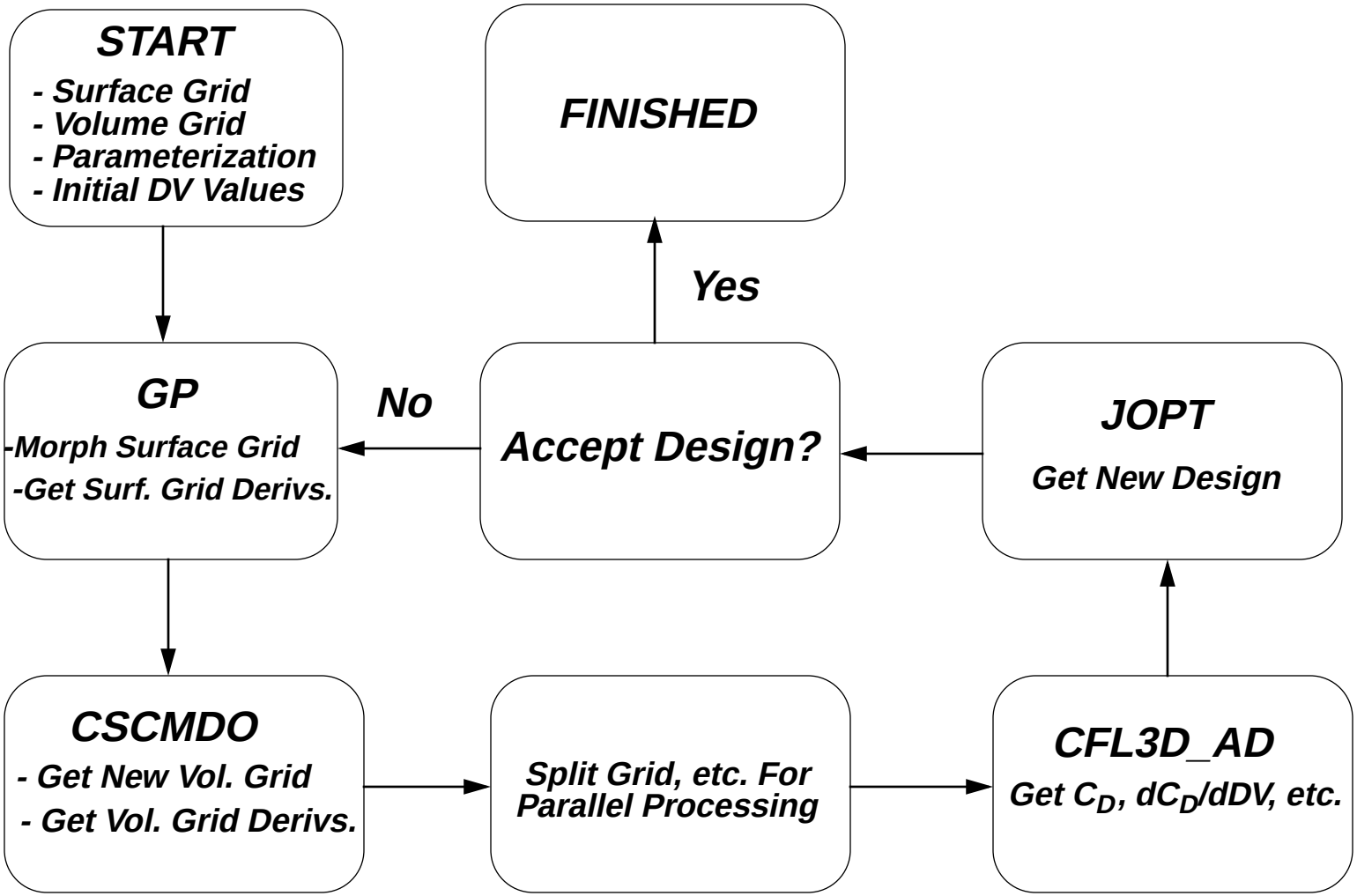
Wing Optimization

- Objective: reduce drag while maintaining same lift as baseline configuration
- 193x33x33 ONERA M6 wing with 31 DVs shown previously
  - Planform variables constrained (area = const)
  - Tip thickness variables constrained to prevent negative cell volumes at tip
- DV bounds: twist +/- 1 deg., all others +/- 1% span
- Flow solver, geometry perturbation codes, and optimizer coupled via UNIX scripts

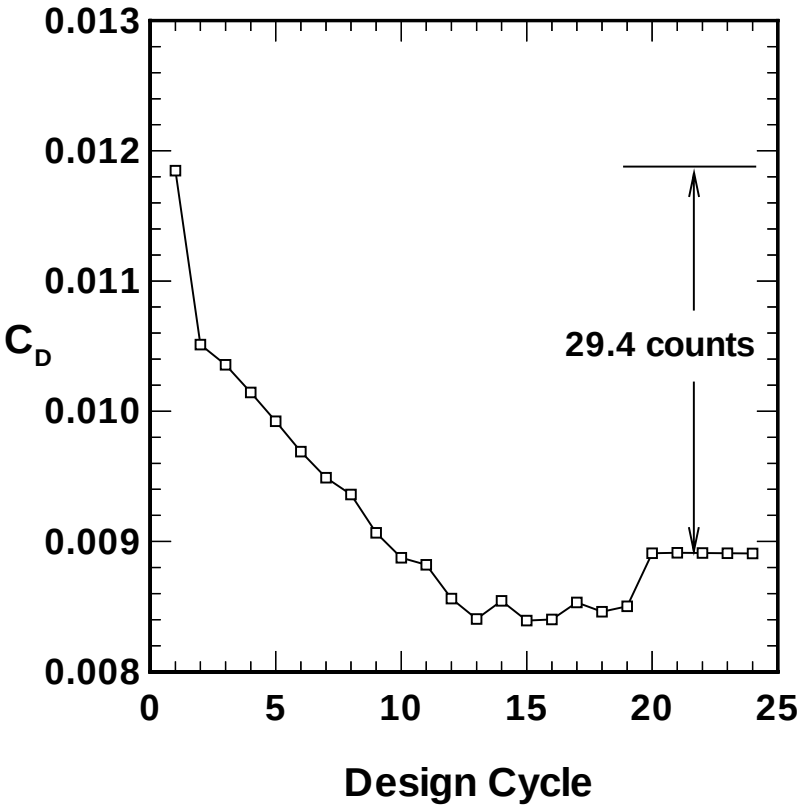
Wing Optimization (cont.)

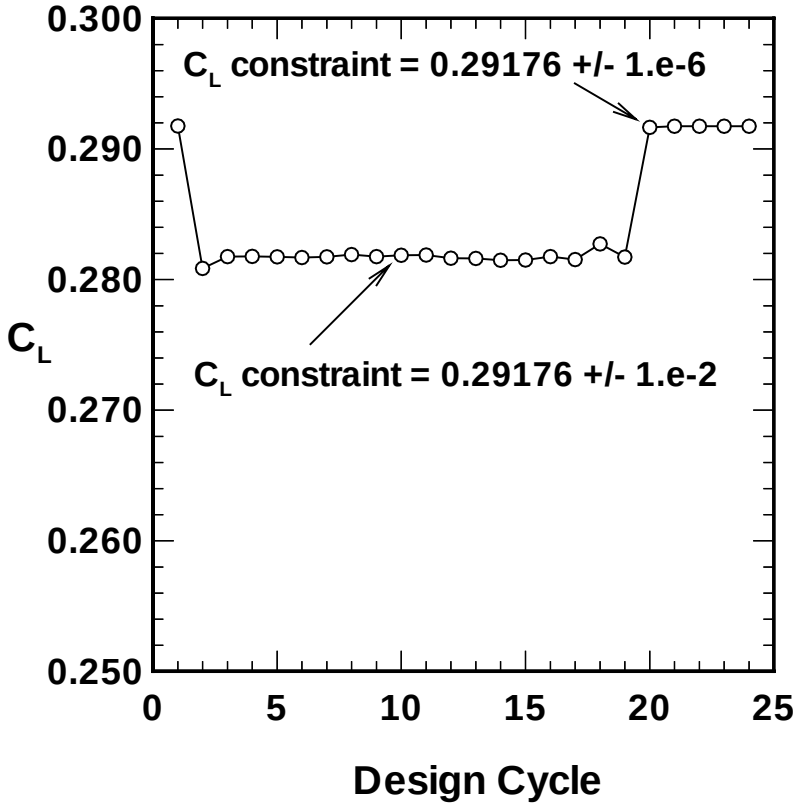
- Optimizer: JOPT = CONMIN + linear approximation to objective function and constraints
  - Linear approx. valid in a limited region around current solution
  - Move limits introduced to keep within linear region; move limits typically << DV bounds
- α not used as a design variable - optimizer would not move away from specified lift value
  - Temporarily relax the lift constraint until minimum drag is reached
  - Tighten constraint to target value for final design

Optimization Flowchart

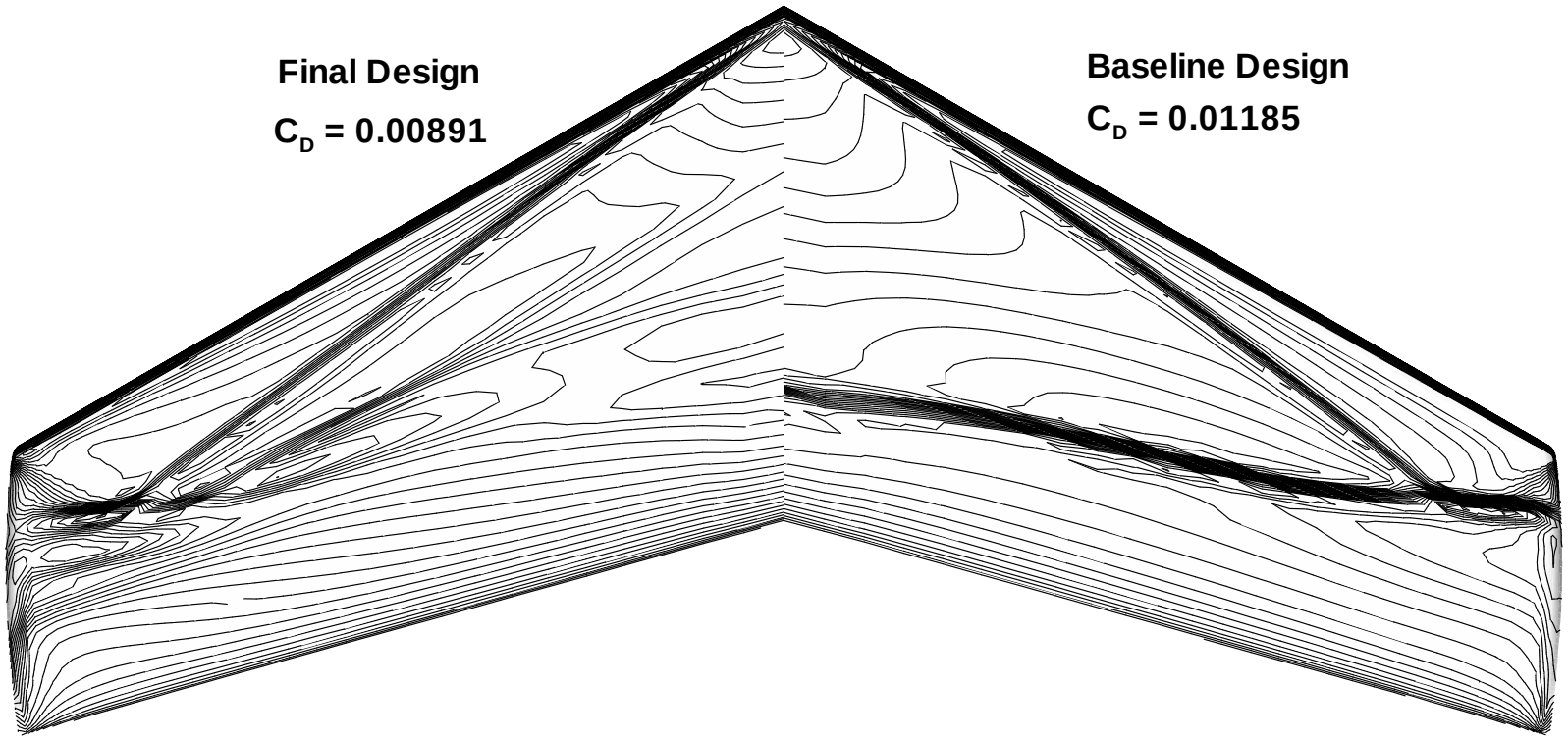


Design Cycle History

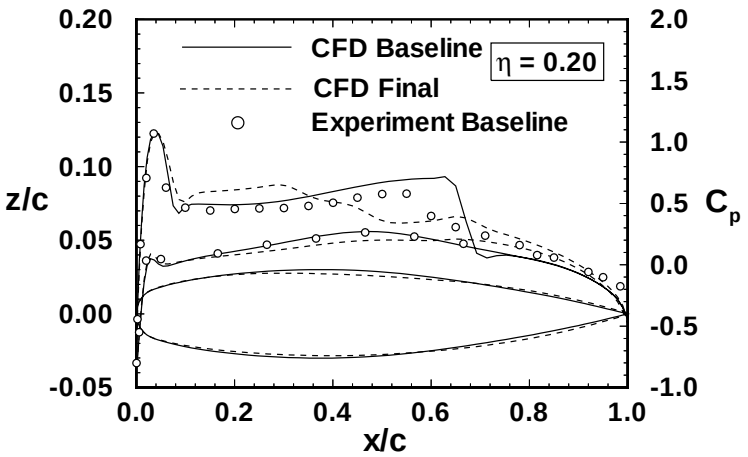


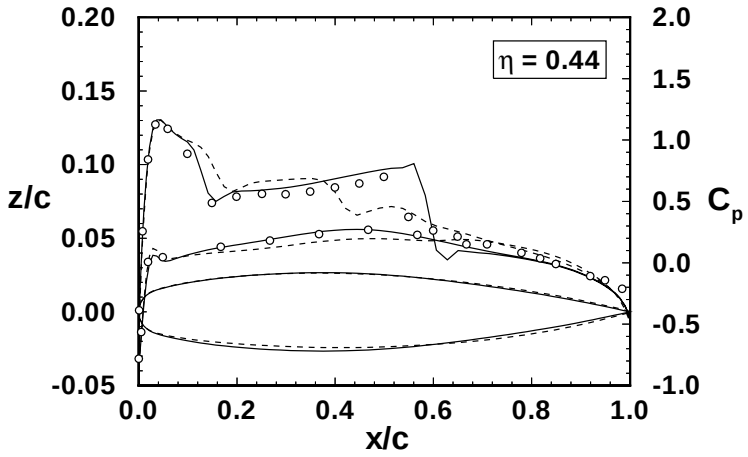


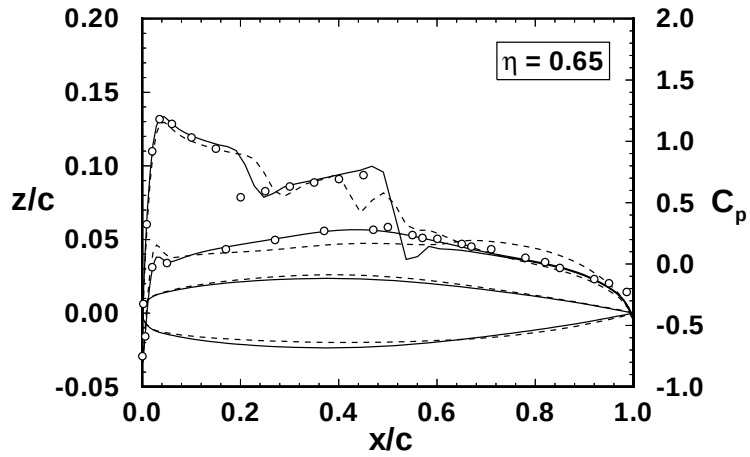
Surface Pressures

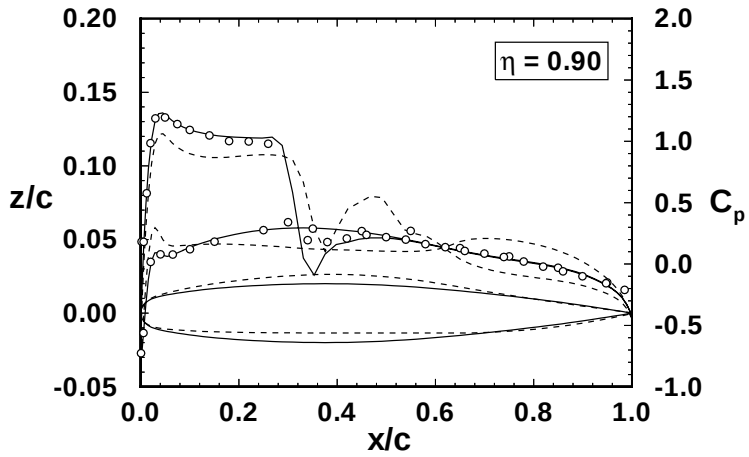


Pressure Coefficients / Wing Sections









Summary

- ADIFOR applied to parallel version of CFL3D - AD derivatives demonstrated to be accurate
- Parallel AD code shown to scale well with number of processors
- Parallel AD code coupled with geometry and optimization packages for optimization problems
- Demonstrated optimization package with 29 count drag reduction on inviscid M6 wing - also applied to HSCT optimization with 540k pts and 27 DVs
- Future applications to include viscous flows